Progress Report of Local Ensemble Kalman Filter/fvGCM on AIRS

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with

References and thanks:

Ott, Hunt, Szunyogh, Zimin, Kostelich, Corazza, Kalnay, Patil, Yorke, 2004: Local Ensemble Kalman Filtering, Tellus, 56A,415–428.

Patil, Hunt, Kalnay, Yorke and Ott, 2001: Local low-dimensionality of atmospheric dynamics, PRL.

Kalnay, 2003: Atmospheric modeling, data assimilation and predictability, Cambridge University Press, 341 pp. (3rd printing)

Hunt, Kalnay, Kostelich, Ott, Szunyogh, Patil, Yorke, Zimin, 2004: Four-dimensional ensemble Kalman filtering. Tellus 56A, 273–277.

Szunyogh, Kostelich, Gyarmati, Hunt, Ott, Zimin, Kalnay, Patil, Yorke, 2004: Assessing a local ensemble Kalman filter: Perfect model experiments with the NCEP global model. Tellus, 56A, in print.

The LEKF algorithm:

1. Make a 6hr ensemble forecast with K+1 members. At each grid point i consider a local 3D volume of ~800km by 800km and a few layers.

2. The expected value of the background is $\overline{}$, the ensemble average, and the $\overline{}$ form the background error covariance **B**. In the subspace of the perturbations, **B** is diagonal, with rank <=K.

3. Use all the observations in the volume and solve exactly the Kalman Filter equations. This gives the analysis $\overline{}$ and the analysis error covariance **A** at the grid point i.

4. Solve the square root equation   and obtain the analysis increments at the grid point i.

5. Transform back   to the grid-point coordinates

6. Create the new initial conditions for the ensemble

7. Go to 1

Ott et al, 2003, Szunyogh et al 2004.
Sauer et al, 2004 extended it to 4DEnKF

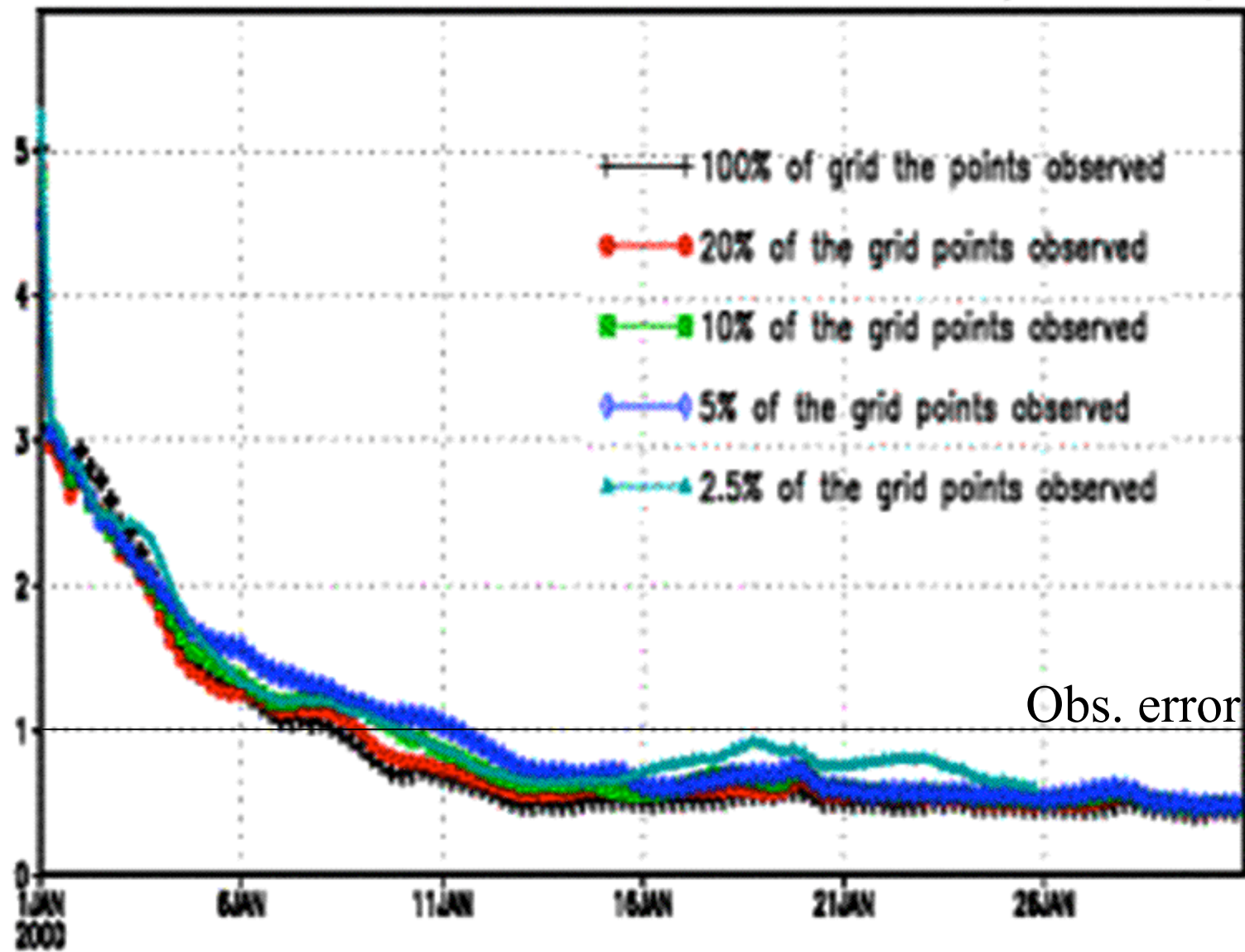# Why use a "local" ensemble approach?

• In the Local Ensemble Kalman Filter we compute the generalized "bred vectors" globally but use them locally.

• These local volumes provide the local shape of the "errors of the day".

• At the end of the local analysis we create a new global analysis and initial perturbations from the solutions obtained at each grid point.

• **This reduces the number of ensemble members needed.**

• **It also allows independent computation of the KF analysis at each grid point.**

From Szunyogh, et al, 2004, Tellus

LEKF results with NCEP's global model

- T62, 28 levels (1.5 million d.o.f.)
- The method is model independent: adapted the same code used for the L40 model as for the NCEP global spectral model
- Simulated observations at every grid point (1.5 million obs)
- Very parallel! Each grid point analysis done independently
- Very fast! 8 minutes in a 25 PC cluster with 40 ensemble members
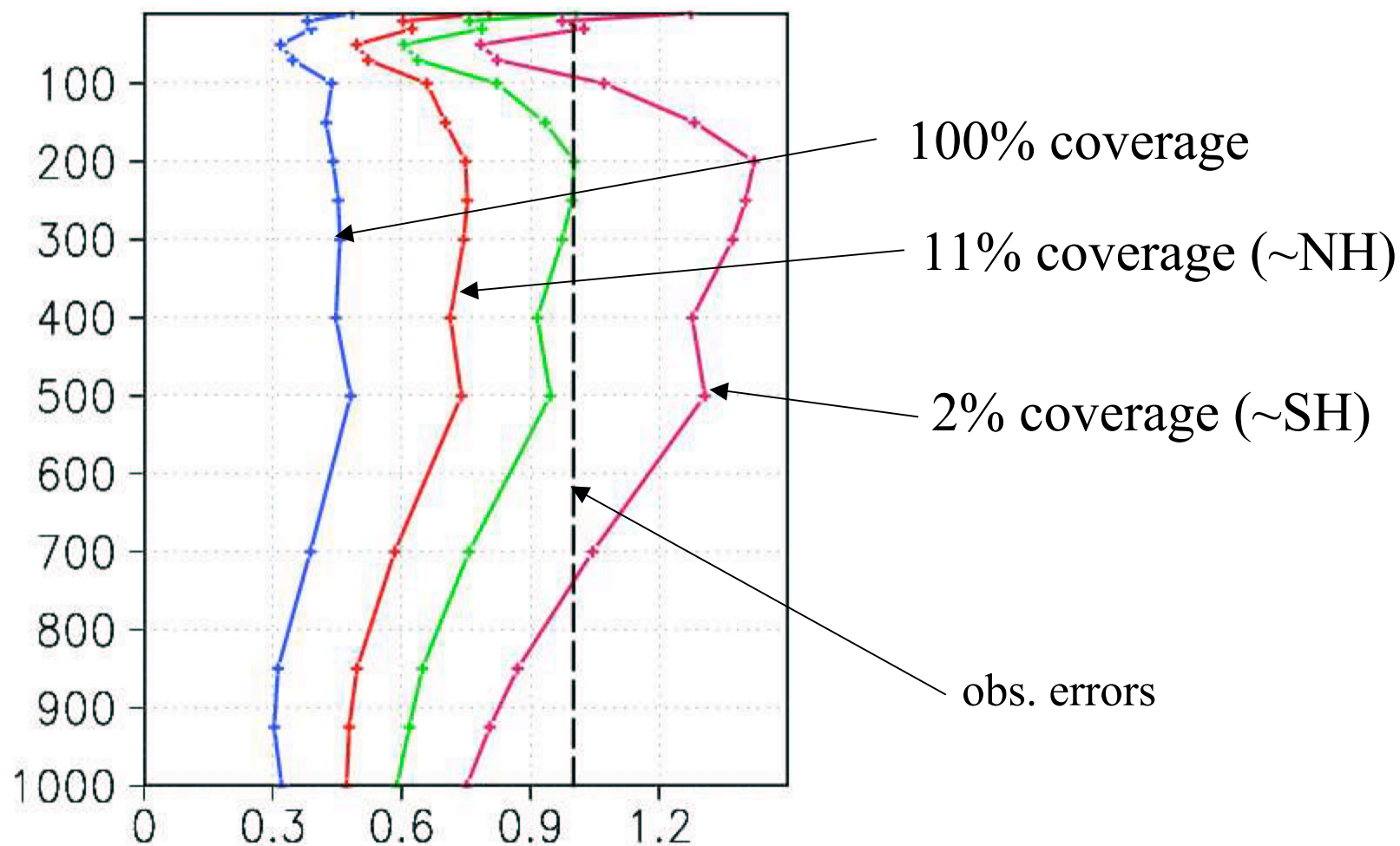
RMS ERROR IN TEMPERATURE ANALYSIS (500 hPa)

100% of grid the points observed
20% of the grid points observed
10% of the grid points observed
5% of the grid points observed
2.5% of the grid points observed

Obs. error

There is a strong relationship between the ensemble E-dimension and the Ob-Fcst explained variance
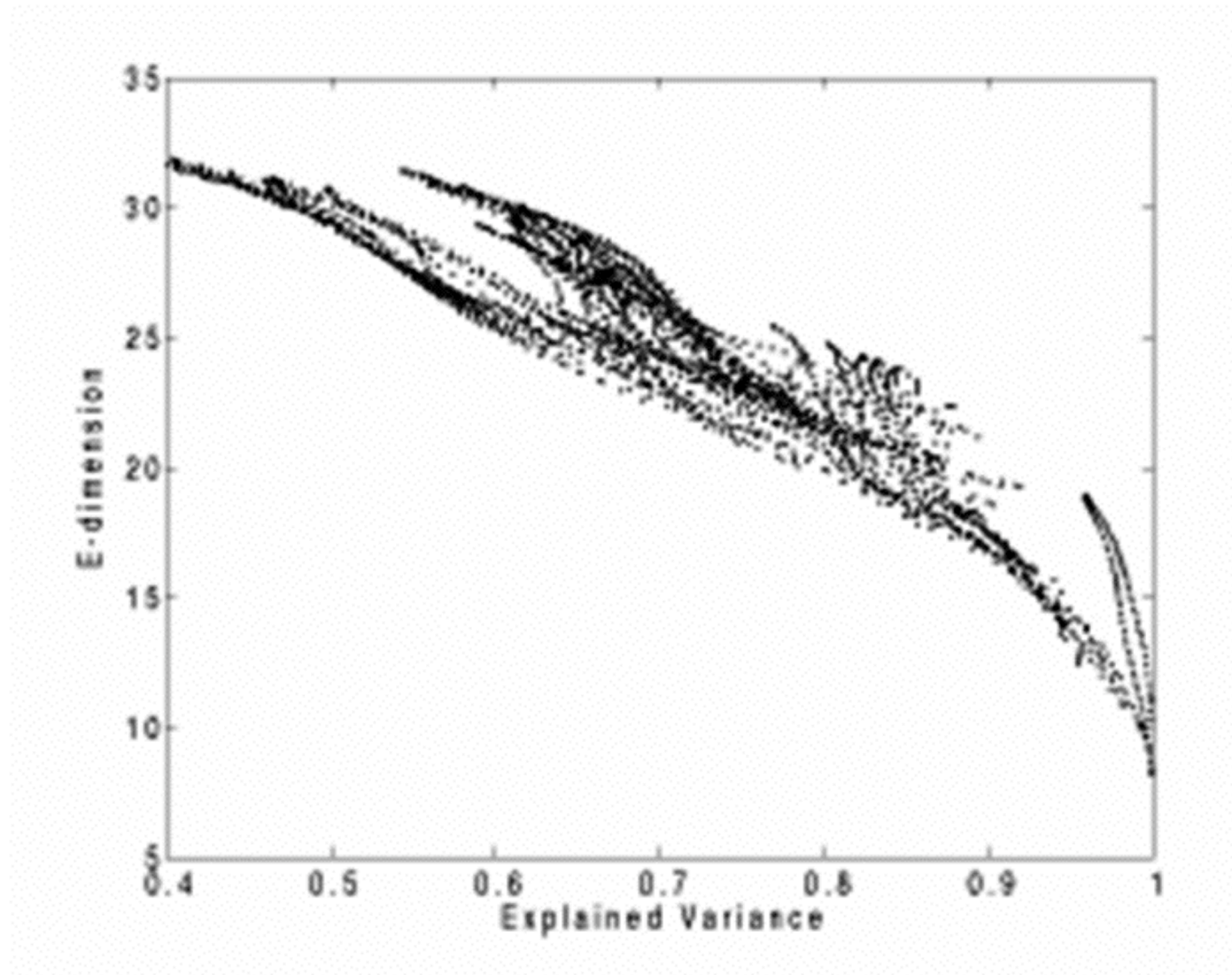
LEKF using 40 ensemble members:
Analysis temperature errors

100% coverage

11% coverage (~NH)

2% coverage (~SH)
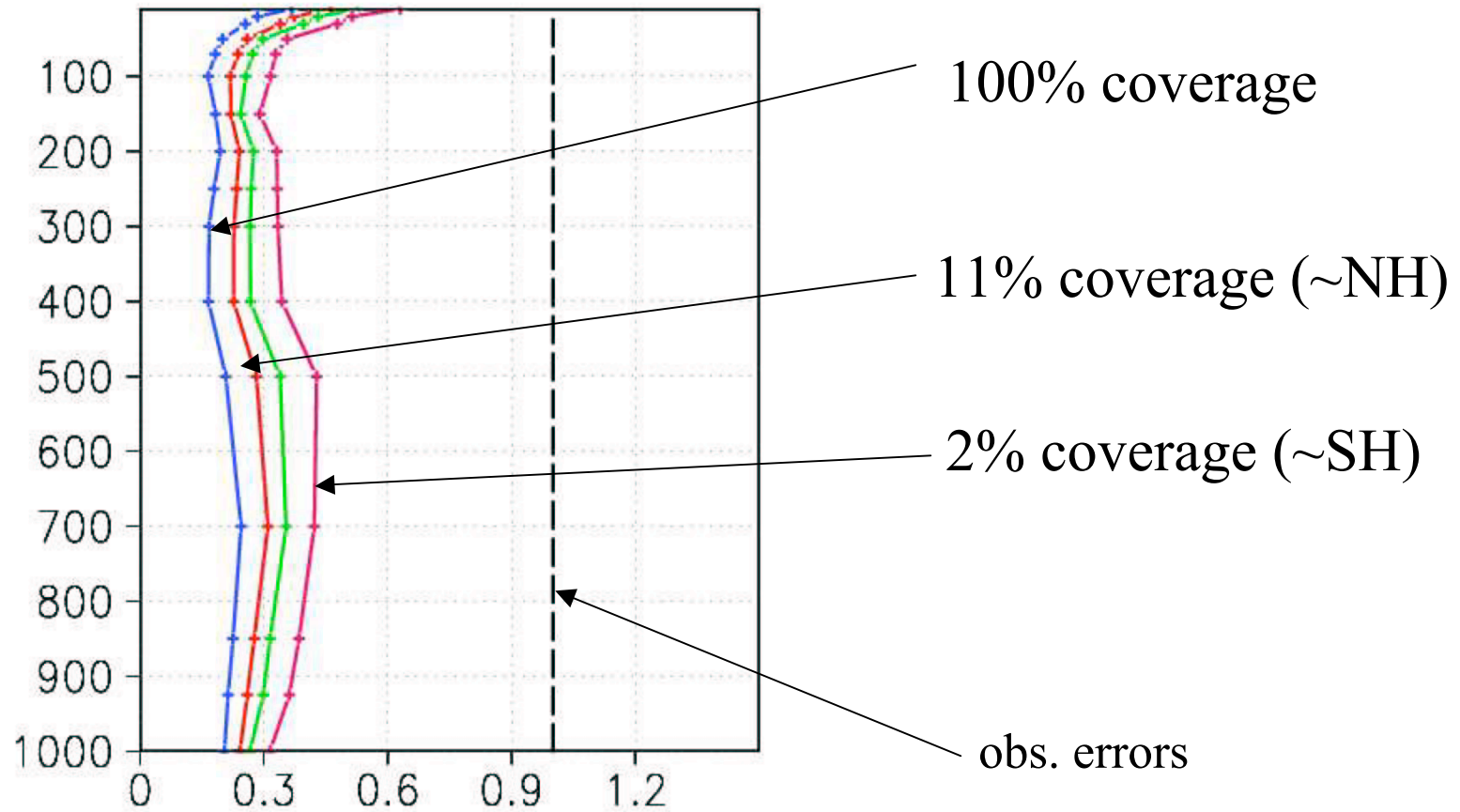
obs. errors

LEKF using 40 ensemble members:
Analysis zonal wind errors (tropics)

100% coverage

11% coverage (~NH)

2% coverage (~SH)

obs. errors

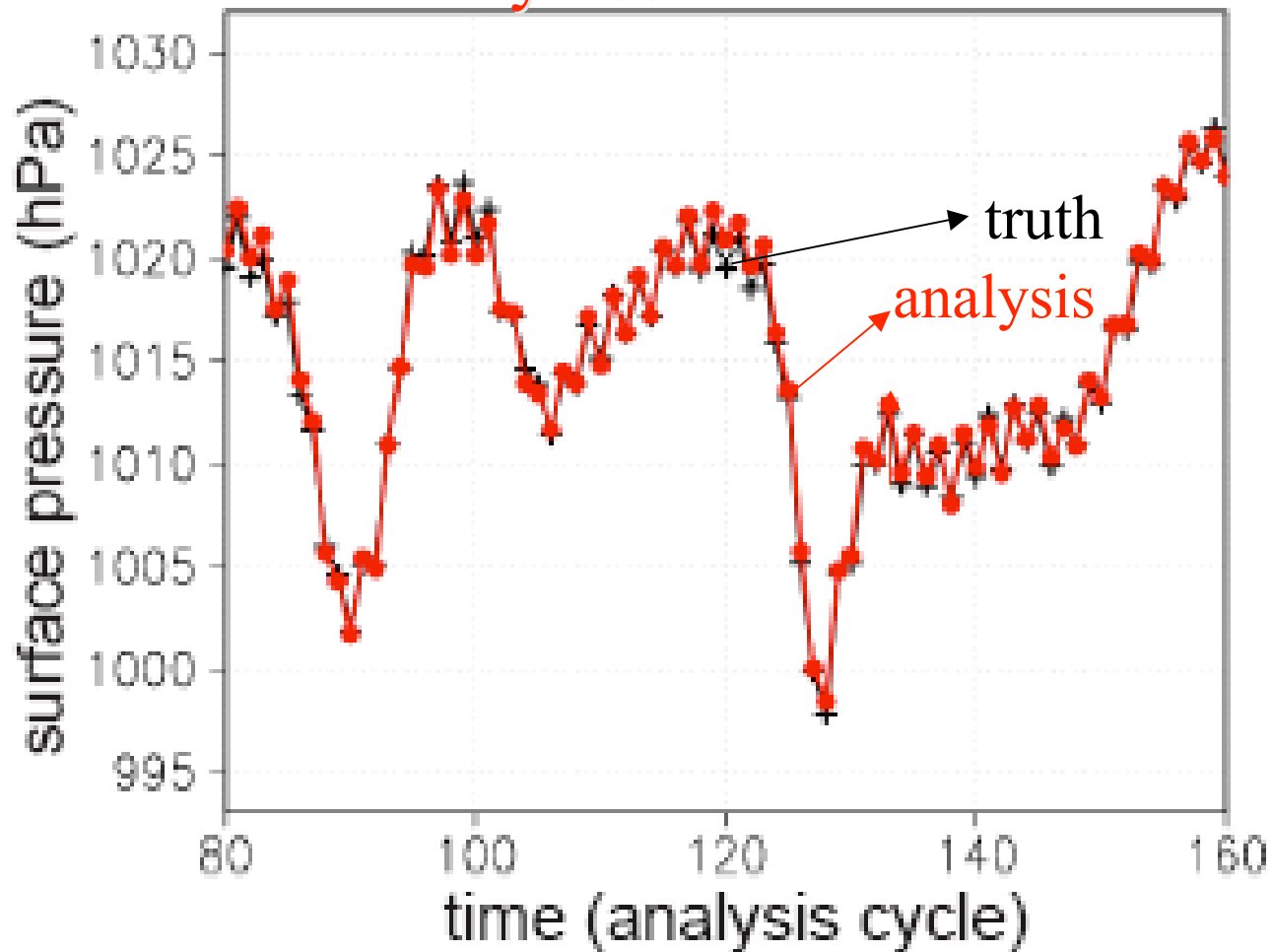# RMS temperature analysis errors
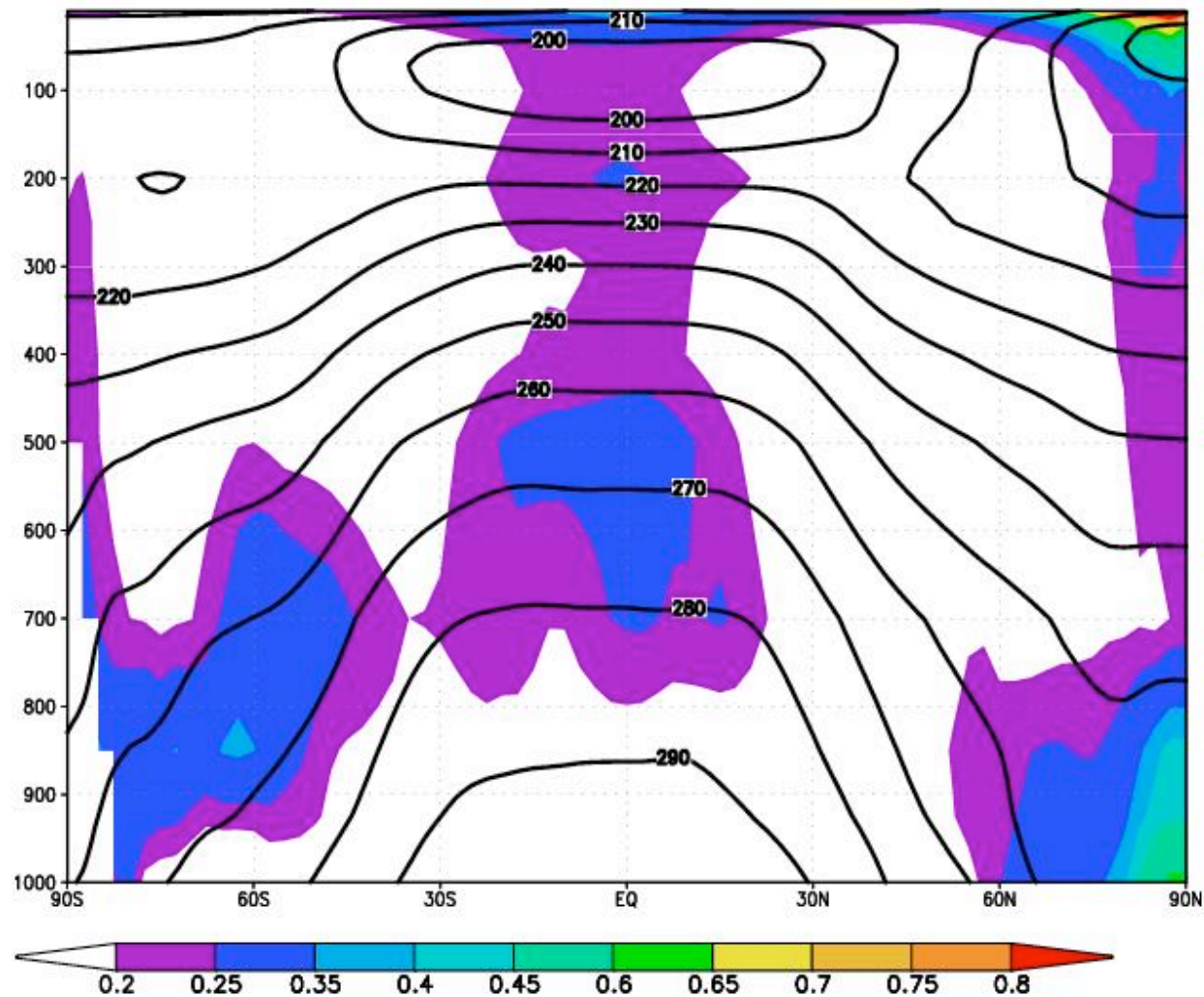
11% coverage

RMS zonal wind analysis errors

11% coverage
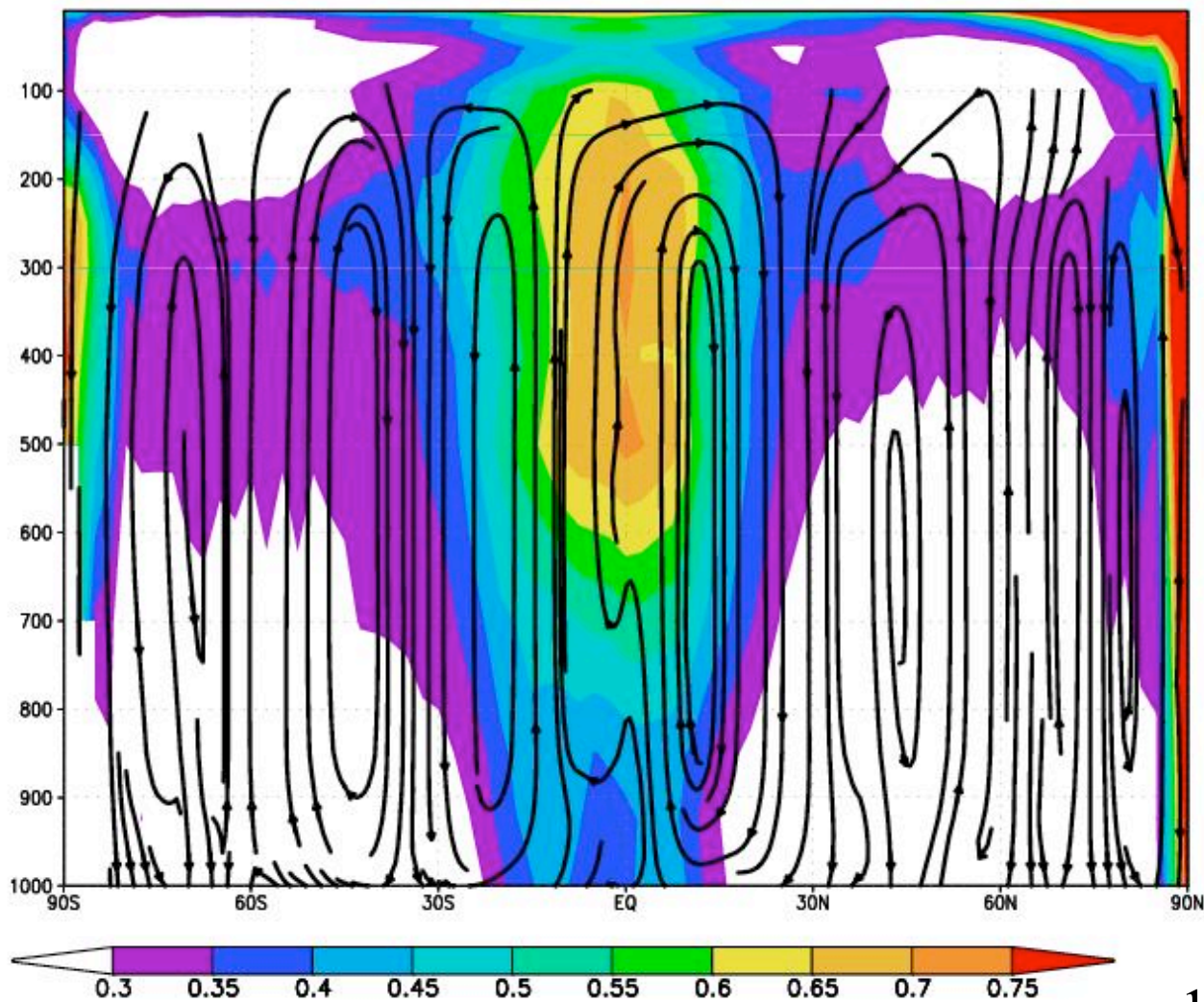
Superbalance: observed gravity wave is reproduced with only 2% observations!!

We could also assimilate Kelvin waves detected by AIRS!!!

Advantages of LEKF

- It knows about the "errors of the day" through **B.**

- Provides **perfect initial perturbations for ensemble forecasting.**

- Free 6 hr forecasts in an ensemble system

- Matrix computations are done in a very low-dimensional space: both <u>accurate</u> and <u>efficient.</u>

- **Does not require adjoint of the NWP model (or the observation operator)**

- Keeps track of the effective ensemble dimension (E-dimension), allowing tuning.

Extensions of LEKF

- Extended to 4DLEKF, to assimilate satellite observations at the right time (Hunt et al, 2004)

- Can be used for adaptive observations

- **Can use advanced nonlinear observation operator H without Jacobian or adjoint** (Szunyogh et al, 2004)

Work in Progress

- Ported fvGCM to our cluster of PC's
- Ported PSAS to our cluster
- Conducted a four month long nature run
- Created simulated observations
- Running PSAS DAS experiments to serve as a baseline
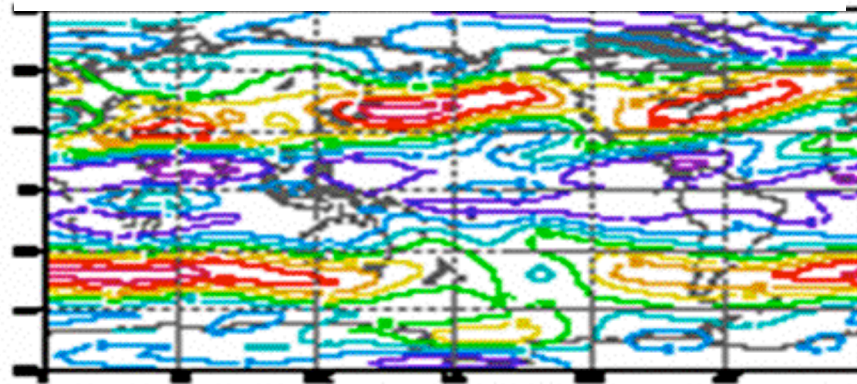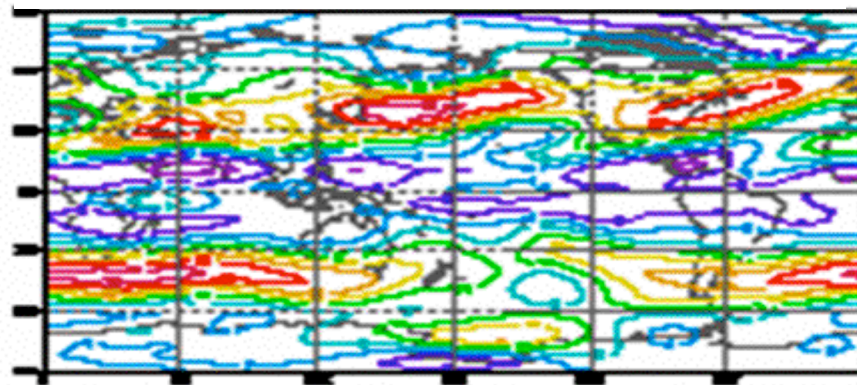- Working on replacing PSAS with LEKF

Simulated Observation Locations
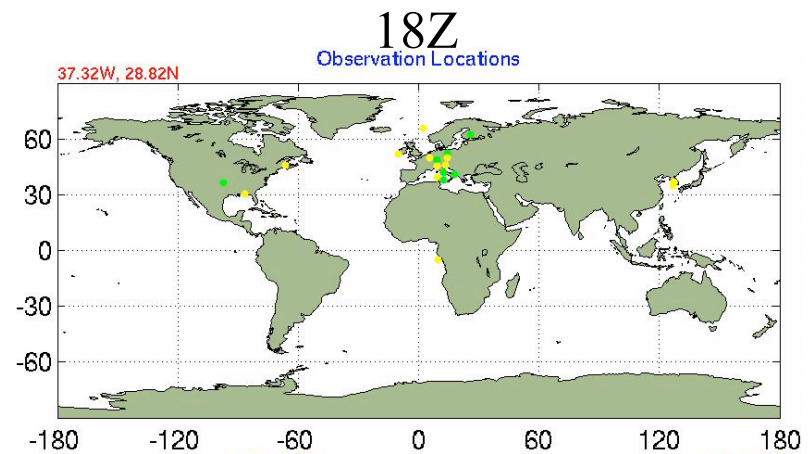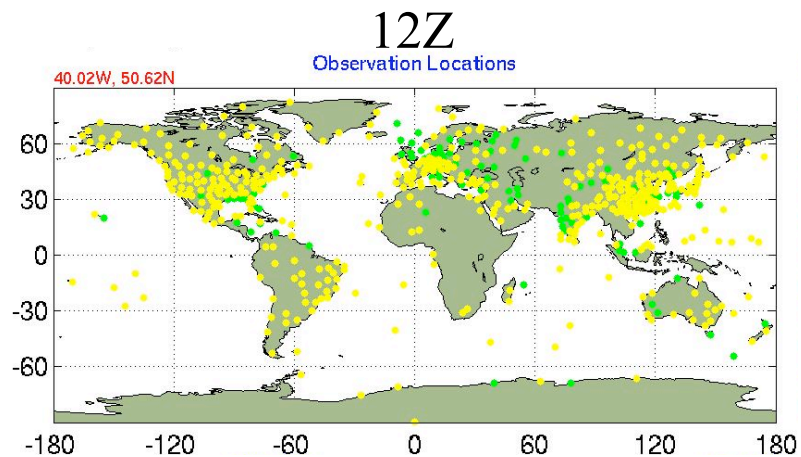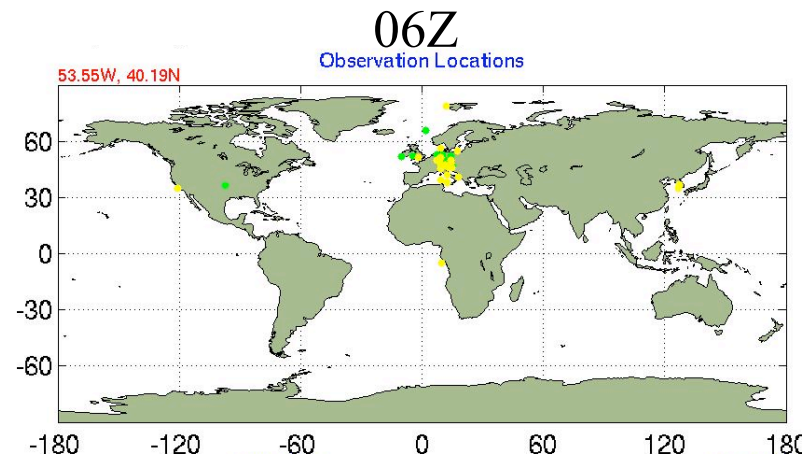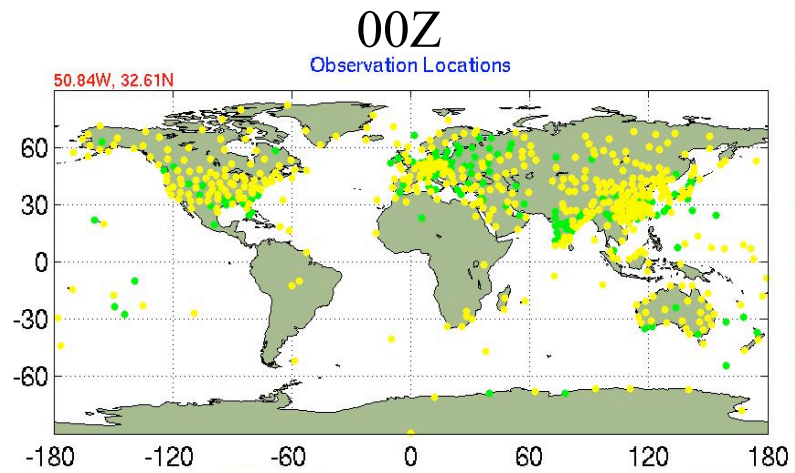
PSAS DAS Experiments
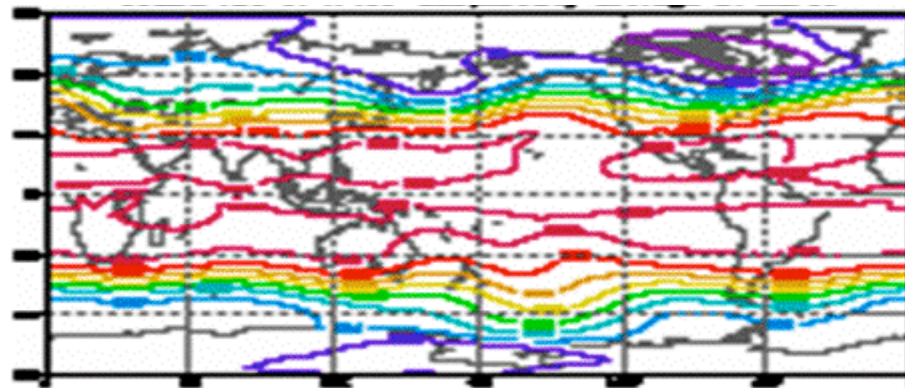
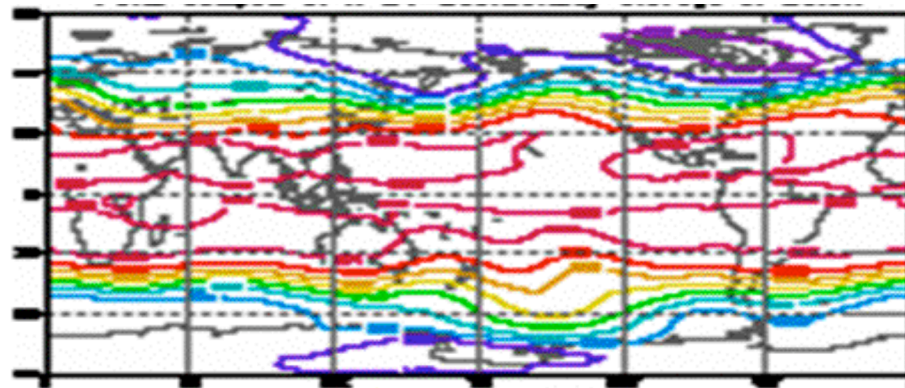## March average of UWND at 500mb

Nature Run

PSAS Run

PSAS DAS Experiments

March average of H at 500mb

Nature Run

PSAS Run

Plans – 1st Year
(by May 2005)

- Complete coupling of the fvGCM system with LEKF

- LEKF DAS experiments with simulated observations

- Comparison with NCEP GFS, NASA PSAS

- Implement real observations on NCEP GFS

Plans – 2nd Year
(by May 2006)

- Assimilate conventional observations on fvGCM system with both LEKF and PSAS

- Compare LEKF with NCEP SSI (3D-Var)

- Implement 4DLEKF to assimilate satellite data at their time of observation

- Start assimilating AIRS data: test nonlinear vs. linearized forward operators
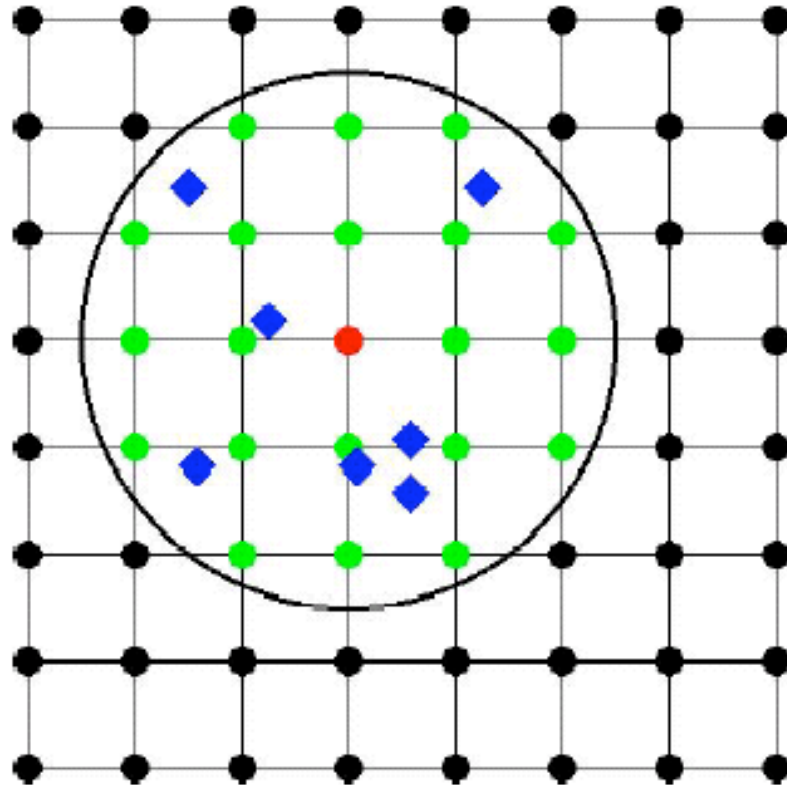
Plans – 3rd Year
(by May 2007)

- Complete 4D-LEKF assimilation of AIRS using best forward operators
- Perform data impact studies with and without AIRS data
- Compare assimilation of AIRS cloud free and cloud cleared radiance data
- Compare the assimilation of AIRS retrievals and of AIRS radiances
- Start assimilating cloud information

We will need guidance from the AIRS Science team

The LEKF algorithm:

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Sauer et al, 2004 extended it to 4DEnKF